Preface

The intent of this book is to serve as an undergraduate textbook in electrodynamics at a basic or advanced level.

The objective is to attain a general understanding of electrodynamic theory and its basic experiments and phenomena in order to form a foundation for further studies in the engineering sciences as well as in modern quantum physics.

The outline of the book is based on the following principles:

- Introduce each phenomenon with relevant and complete experiments
- Focus on experiments and observations accessible to the student
- Base the theory on the concept of force and mutual interaction
- Present electrodynamics using the same principles as in the preceding mechanics course
- Treat electric, magnetic and inductive phenomena cohesively with respect to force, energy, dipoles and material
- Aim at explaining that theory of relativity is based on the magnetic effect
- Introduce field theory *after* the basic phenomena have been explored in terms of force.

Overview

The book starts by considering the different types of forces that occur between electric charges. These may be directly related to their motion, i.e. charges at rest, in uniform motion and in acceleration. The forces, known as electric, magnetic and inductive, are treated cohesively and formulated through observations and measurements. The subsequent chapters are more or less direct applications of the force formulas.

Chapter 3 introduces the energy concept as a direct consequence of force through the principle of work. The inductive force is then utilized to derive magnetic energy. Neumann's formula for inductance is fully derived and used to express magnetic energy.

Chapter 4 covers macroscopic systems whose characteristics are obtained through a summation of mutual interactions between infinitesimal elements of charge. Calculation techniques for capacitance and inductance are introduced and shown to be useful concepts in case the system is homogeneous.

Chapters 5 and 6 deal with the conductor and electric circuits which constitute the experimental environment from which electrodynamics was developed and technical applications originated. The microscopic description of electric conduction, the origin of resistance and its relation to heat are treated first. Then the resonance circuit which includes the other two circuit components, capacitance and inductance, is introduced.

Chapter 7 introduces electric and magnetic dipoles, which are significant concepts since nature generally may be described in terms of such objects. The expressions for electric and magnetic dipole–dipole interaction energies are then central to providing both force and torque.

Chapter 8 investigates how different electrically and magnetically neutral materials respond to electric and magnetic influences. It is then assumed that the material is composed of dipoles. The material parameters are introduced and techniques for measuring them are described. A mathematically rigorous treatment of the dipole, or generally multipole, interactions is presented in the accompanying Appendices A and B.

In Chap. 9, it is shown conceptually how the magnetic and inductive dynamics arise as motional consequences of the electric force assuming that interactions take time; they are mediated at the speed of light. Alternatively, one may utilize the knowledge of electric and magnetic forces to derive the speed of light. In a special case both the magnetic force and the Faraday-Henry's law of induction are derived. It is also shown how electromagnetic dynamics is related to relativity, using the fact that magnetism is the motional consequence on which the special theory of relativity is based. Since we build the theory upon the concept of force the material is unique to this book. Chapter 9 also introduces Lorentz transformation in the form of a tutorial. Prerequisites of Chap. 9 are only Chaps. 1–3, thus these four chapters may form a concise course in basic electrodynamics and its relation to relativity.

In Chap. 10, electromagnetic field theory is introduced and Maxwell's equations formulated. The fields are indeed already defined by the force formulas, but expressed in Maxwell's equations in terms of their divergence and curl. This is motivated by showing that the boundary conditions of the fields are then defined. Using the fields, the Poynting vector may be formulated corresponding to the power transported from an electrodynamic system.

An important feature of this book is thus that field theory is introduced after the physical phenomena that constitute electrodynamics have been described, interpreted and formulated in terms of fundamental forces.

In Chap. 11, antenna theory is introduced using the principle of retarded interactions, i.e. taking into account that interactions take time. The small loop and the small wire antennas are treated assuming current is uniform and varies harmonically with time. Furthermore, the antenna array is discussed. The basic principles of retarded interactions and array effects are thus developed and may then be applied to natural oscillators as are found in nature. In this way, the reflection law, the refraction law and the phenomenon of Brewster reflection are derived and fully explained. The power delivered by an antenna is also analysed using the Poynting vector derived in a previous chapter.

Appendix D contains solutions to the exercises appearing in the book.

Prerequisites and Target Audience

Although electrodynamics is described in this book from its first principles, prior knowledge of about one semester of university studies in mathematics and physics is required, including vector algebra, integral and differential calculus as well as a course in mechanics, treating Newton's laws and the energy principle. The target groups are teachers, engineering and physics students as well as professionals in the field, e.g. high-school teachers and employees in the telecom industry. Also chemistry and computer science students may benefit from the book.

Study Tips

Learning physics inevitably implies active involvement, especially in problem-solving and experimental studies. We recommend that the discussed experiments also be implemented in practice, not least to avoid tendencies to abstraction.

Some of the exercises, marked with an asterisk, are included in the theory of the book and need to be solved before the chapter that follows them. The exercises marked with a 'C' are more challenging and normally not suitable for independent problem solving.

A solution manual is included in Appendix D.

Website

The book has a website where you will find reader comments, recommended Internet links, videos on relevant experiments/phenomena, further exercises and suggested laboratory work. Please consult the publisher's website to obtain the relevant web address.

Acknowledgment

I want to express my gratitude to all students who contributed so much to the courses I have given over the years, including everything from basic and advanced electromagnetic courses to theory of relativity and application courses in Antenna and Microwave engineering at different levels in different study programs. The reflections, comments and questions I have received from them have been of crucial importance for my own development and the genesis of this book. I would also like to thank my colleagues for many intense and fruitful discussions on Physics in general and its role in society. Many interesting conversations with lecturers Göran Nordström on the subject's didactics and Peter Johansson on the connection between relativity and electrodynamics have been indispensable for me. The latter coined the term 'motional consequence' which is diligently used in this book. Many thanks to Dr. Jenny Ivarsson for a thorough scientific review of a first version of this book and to engineering student Nicklas Bjärnhall Prytz for indispensable advice on pedagogical issues as well as for making this book readable in English.

This book was originally published in Swedish and is available from its publisher Studentlitteratur. I appreciate all their support during the work, in particular with the drawing of the figures.

Finally, I would like to thank the Springer staff for all their support during the translation and revision of the book.

2014 Kjell Prytz

http://www.springer.com/978-3-319-13170-2

Electrodynamics: The Field-Free Approach
Electrostatics, Magnetism, Induction, Relativity and
Field Theory
Prytz, K.
2015, XXV, 361 p. 204 illus., 4 illus. in color., Hardcover
ISBN: 978-3-319-13170-2